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IN THE SPECIFICATION:

Please amend the specification as follows:

[0015] For achieving the object, ~~claim 1~~ a first aspect of the invention defines an ultrafine crystal layer forming process of forming an ultrafine crystal layer in a surface layer portion of a surface of a workpiece constituted by a metallic material, by performing a machining operation on the surface of the workpiece using a machining tool, so as to impart a large local strain to the machined surface of the workpiece, wherein the machining operation using the machining tool causes the machined surface of the workpiece to be subjected to a plastic working that causes the machined surface of the workpiece to have a true strain of at least 1.

[0016] According to ~~claim 2~~ a second aspect of the invention, in the ultrafine crystal layer forming process defined in ~~claim 1~~ the first aspect of the invention, the machining operation using the machining tool is performed with a material temperature at the machined surface of the workpiece being held lower than a predetermined upper limit temperature, wherein the predetermined upper limit temperature is, where the workpiece is constituted by a steel material, an Ac1 transformation point of the steel material, and wherein the predetermined upper limit temperature is, where the workpiece is constituted by the metallic material other than the steel material, substantially half a melting point of the

metallic material as expressed in terms of absolute temperature.

[0017] According to ~~claim 3~~ a third aspect of the invention, in the ultrafine crystal layer forming process defined in ~~claim 1~~ the first aspect of the invention, the machining operation using the machining tool is performed with a material temperature at the machined surface of the workpiece being held within a predetermined temperature range, wherein the predetermined temperature range is, where the workpiece is constituted by a steel material, not lower than an Ac1 transformation point of the steel material and is lower than a melting point of the steel material, and wherein the predetermined temperature range is, where the workpiece is constituted by the metallic material other than the steel material, not lower than substantially half a melting point of the metallic material as expressed in terms of absolute temperature and is lower than the melting point of the metallic material.

[0018] According to ~~claim 4~~ a fourth aspect of the invention, in the ultrafine crystal layer forming process defined in ~~claim 3~~ the third aspect of the invention, where the workpiece is constituted by the steel material, after the machining operation using the machining tool has been performed, the machined surface of the workpiece is cooled at

a rate higher than a cooling rate that is required for hardening the workpiece.

[0019] According to ~~claim 5~~ a fifth aspect of the invention, in the ultrafine crystal layer forming process defined in any one of ~~claims 2-4~~ the second through fourth aspects of the invention, the machining operation using the machining tool is performed, such that a material temperature at the machined surface of the workpiece is held lower than the predetermined upper limit temperature or held within the predetermined temperature range, and such that a material temperature at a non-ultrafine crystal layer which is provided by a lower layer portion of the machined surface or which is provided by a surface layer portion in neighborhood of the machined surface is held at least about 500 C° for a length of time that is not larger than about 1 second, for providing the non-ultrafine crystal layer with a hardness that is about 80 % as high as a hardness of a substrate of the workpiece.

[0020] ~~Claim 6~~ A sixth aspect of the invention defines a machine component constituted by a metallic material and having a surface layer portion, wherein the surface layer portion is at least partially provided by an ultrafine crystal layer formed by the ultrafine crystal layer forming process defined in any one of ~~claims 1-5~~ the first through fifth aspects of the invention.

[0021] ~~Claim 7~~ A seventh aspect of the invention defines a machine component producing process of producing a machine component constituted by a metallic material and having a surface layer portion that is at least partially provided by an ultrafine crystal layer, wherein the process includes at least an ultrafine crystal layer forming step of forming the ultrafine crystal layer in the machine component by the ultrafine crystal layer forming process defined in any one of ~~claims 1-5~~ the first through fifth aspects of the invention.

[0022] ~~Claim 8~~ An eighth aspect of the invention defines a nanocrystal layer forming process of forming a nanocrystal layer in a surface layer portion of a surface of a workpiece constituted by a metallic material, by performing a machining operation on the surface of the workpiece using a machining tool, so as to impart a large local strain to the machined surface of the workpiece, wherein the machining operation using the machining tool causes the machined surface of the workpiece to be subjected to a plastic working that causes the machined surface of the workpiece to have a true strain of at least 7, and is performed with a material temperature at the machined surface of the workpiece being held within a predetermined temperature range, wherein the predetermined temperature range is, where the workpiece is constituted by a steel material, not lower than an Ac1 transformation point of the steel material and is lower than a melting point of the

steel material, and wherein the predetermined temperature range is, where the workpiece is constituted by the metallic material other than the steel material, not lower than substantially half a melting point of the metallic material as expressed in terms of absolute temperature and is lower than the melting point of the metallic material.

[0023] According to ~~claim 9~~ a ninth aspect of the invention, in the nanocrystal layer forming process defined in ~~claim 8~~ the eighth aspect of the invention, wherein the machining operation using the machining tool is performed, such that a material temperature at the machined surface of the workpiece is held within the predetermined temperature range, and such that a material temperature at a non-nanocrystal layer which is provided by a lower layer portion of the machined surface or which is provided by a surface layer portion in neighborhood of the machined surface is held at least about 500 C° for a length of time that is not larger than about 1 second, for providing the nanocrystal layer with a hardness that is about 80 % as high as a hardness of a substrate of the workpiece.

[0024] ~~Claim 10~~ A tenth aspect of the invention defines a nanocrystal layer forming process of forming a nanocrystal layer as a fine crystal grain layer in a surface of a workpiece constituted by a metallic material, wherein the process includes performing a machining operation on the

surface of the workpiece using a machining tool, so as to impart a large local strain to the machined surface of the workpiece, for forming the nanocrystal layer in a surface layer portion of the machined surface of the workpiece.

[0025] According to ~~claim 11~~ an eleventh aspect of the invention, in the nanocrystal layer forming process defined in ~~claim 12~~ the tenth aspect of the invention, wherein the machining operation using the machining tool causes the machined surface of the workpiece to be subjected to a plastic working that causes the machined surface of the workpiece to have a true strain of at least 7, and is performed with a material temperature at the machined surface of the workpiece being held not higher than a predetermined upper limit temperature, wherein the predetermined upper limit temperature is, where the workpiece is constituted by a steel material, A1 and A3 transformation points of the steel material, and wherein the predetermined upper limit temperature is, where the workpiece is constituted by the metallic material other than the steel material, substantially half a melting point of the metallic material as expressed in terms of absolute temperature.

[0026] According to ~~claim 12~~ a twelfth aspect of the invention, in the nanocrystal layer forming process defined in ~~claim 11~~ the eleventh aspect of the invention, the material temperature at the machined surface of the workpiece is held

such that an overall time-based average value of the material temperature during the machining operation and an overall surface-based average value of the material temperature in an entirety of the machined surface over which a heat is distributed are not higher than the predetermined upper limit temperature.

[0027] According to ~~claim 13~~ a thirteenth aspect of the invention, in the nanocrystal layer forming process defined in any one of ~~claims 8-12~~ the eighth through twelfth aspects of the invention, wherein the machining operation using the machining tool is performed such that a strain gradient of at least 1 / ìm is imparted to the surface layer portion of the machined surface.

[0028] ~~Claim 14~~ A fourteenth aspect of the invention defines a machine component constituted by a metallic material and having a surface layer portion, wherein the surface layer portion is at least partially provided by a nanocrystal layer formed by the nanocrystal layer forming process defined in any one of ~~claims 8-13~~ the eighth through thirteenth aspects of the invention.

[0029] ~~Claim 15~~ A fifteenth aspect of the invention defines a machine component producing process of producing a machine component constituted by a metallic material and having a surface layer portion that is at least partially provided by a nanocrystal layer, wherein the process included

at least a nanocrystal layer forming step of forming the nanocrystal layer in the machine component by the nanocrystal layer forming process defined in any one of ~~claims 8-13~~ the eighth through thirteenth aspects of the invention.

[0030] In the ultrafine crystal layer forming process defined in ~~claim 1~~ the first aspect of the invention, since the ultrafine crystal layer is formed in the surface layer portion of the machined surface by performing the machining operation using the machining tool, it is possible to restrain the problems, encountered in the conventional techniques, that portions of a workpiece in which the ultrafine crystal layer can be formed are limited depending upon a shape of the workpiece and that the thickness and characteristics of the ultrafine crystal layer are not uniform, Consequently, the ultrafine crystal layer forming process provides an effect that makes it possible to stably form the ultrafine crystal layer forming process in the workpiece such as a machine component.

[0032] Further, in the conventional techniques, where the ultrafine crystal layer is to be formed over a wide area, the collision of the protrusion or the hard particles has to be repeated a plurality of times, thereby increasing a required forming time and resulting in inefficiency in the formation of the ultrafine crystal layer. On the other hand, in the ultrafine crystal layer forming process defined in ~~claim 1~~ the

first aspect of the invention, since the ultrafine crystal layer is formed by performing the machining operation using the machining tool, it is possible to efficiently form the ultrafine crystal layer, leading to the consequent reduction in the cost for the formation of the ultrafine crystal layer.

[0034] In the ultrafine crystal layer forming process defined in ~~claim 2~~ the second aspect of the invention, in addition to the effects provided in the ultrafine crystal layer forming process defined in ~~claim 1~~ the first aspect of the invention, the machining operation using the machining tool is performed with a material temperature at the machined surface of the workpiece being held lower than a predetermined upper limit temperature, wherein the predetermined upper limit temperature is, where the workpiece is constituted by a steel material, an Ac1 transformation point of the steel material, and wherein the predetermined upper limit temperature is, where the workpiece is constituted by the metallic material other than the steel material, substantially half a melting point of the metallic material as expressed in terms of absolute temperature. Consequently, there is an effect that it is possible to stably form the ultrafine crystal layer in the surface layer portion of the machined surface of the workpiece that is constituted by a material having a relatively low hardness.

[0035] In the ultrafine crystal layer forming process defined in ~~claim 3~~ the third aspect of the invention, in addition to the effects provided in the ultrafine crystal layer forming process defined in ~~claim 1~~ the first aspect of the invention, the machining operation using the machining tool is performed with a material temperature at the machined surface of the workpiece being held within a predetermined temperature range, wherein the predetermined temperature range is, where the workpiece is constituted by a steel material, not lower than an Ac1 transformation point of the steel material and is lower than a melting point of the steel material, and wherein the predetermined temperature range is, where the workpiece is constituted by the metallic material other than the steel material, not lower than substantially half a melting point of the metallic material as expressed in terms of absolute temperature and is lower than the melting point of the metallic material.

[0037] In the ultrafine crystal layer forming process defined in ~~claim 4~~ the fourth aspect of the invention, in addition to the effects provided in the ultrafine crystal layer forming process defined in ~~claim 3~~ the third aspect of the invention, where the workpiece is constituted by the steel material, after the machining operation using the machining tool has been performed, the machined surface of the workpiece is cooled at a rate higher than a cooling rate that is

required for hardening the workpiece. Thus, there is an effect that the hardness of the ultrafine crystal layer can be held high.

[0038] In the ultrafine crystal layer forming process defined in ~~claim 5~~ the fifth aspect of the invention, in addition to the effects provided in the ultrafine crystal layer forming process defined in any one of ~~claims 2-4~~ the second through fourth aspects of the invention, the machining operation using the machining tool is performed, such that a material temperature at the machined surface of the workpiece is held lower than the predetermined upper limit temperature or held within the predetermined temperature range, and such that a material temperature at a non-ultrafine crystal layer which is provided by a lower layer portion of the machined surface or which is provided by a surface layer portion in neighborhood of the machined surface is held at least about 500 C° for a length of time that is not larger than about 1 second, for providing the non-ultrafine crystal layer with a hardness that is about 80 % as high as a hardness of a substrate of the workpiece.

[0040] In the machine component defined in ~~claim 6~~ the sixth aspect of the invention, the surface layer portion is at least partially provided by the ultrafine crystal layer formed by the ultrafine crystal layer forming process defined in any one of ~~claims 1-5~~ the first through fifth aspects of the

invention. Thus, it is possible to improve a surface hardness of the machine component, and to improve a fatigue strength of the machine component owing to a compressive residual stress imparted thereto. Further, a wear resistance of the machine component can be improved, since it becomes hard to be recrystallized even under a high temperature. Consequently, there is an effect that makes it possible to improve the characteristics of the machine component.

[0041] Further, since the ultrafine crystal layer is formed by the ultrafine crystal layer forming process defined in any one of ~~claims 1-5~~ the first through fifth aspects of the invention, the ultrafine crystal layer can be formed at a low cost, there is an effect that a cost for the entirety of the machine component as a product can be restrained owing to the formation of the ultrafine crystal layer at the low cost.

[0042] In the machine component producing process defined in ~~claim 7~~ the seventh aspect of the invention, since there is provided at least the ultrafine crystal layer forming step of forming the ultrafine crystal layer in the machine component through the ultrafine crystal layer forming process defined in any one of ~~claims 1-5~~ the first through fifth aspects of the invention, there is an effect that the machine component can be produced with the ultrafine crystal layer being stably formed at a restrained cost.

[0043] In the nanocrystal layer forming process defined in ~~claim 8~~ the eighth aspect of the invention, since the nanocrystal layer is formed in the surface layer portion of the machined surface by performing the machining operation using the machining tool, it is possible to restrain the problems, encountered in the conventional techniques, that portions of a workpiece in which the nanocrystal layer can be formed are limited depending upon a shape of the workpiece and that the thickness and characteristics of the nanocrystal layer are not uniform, Consequently, the nanocrystal layer forming process provides an effect that makes it possible to stably form the nanocrystal layer forming process in the workpiece such as a machine component.

[0045] Further, in the conventional techniques, where the nanocrystal layer is to be formed over a wide area, the collision of the protrusion or the hard particles has to be repeated a plurality of times, thereby increasing a required forming time and resulting in inefficiency in the formation of the nanocrystal layer. On the other hand, in the nanocrystal layer forming process defined in ~~claim 1~~ the eighth aspect of the invention, since the nanocrystal layer is formed by performing the machining operation using the machining tool, it is possible to efficiently form the nanocrystal layer, leading to the consequent reduction in the cost for the formation of the nanocrystal layer.

[0048] In the nanocrystal layer forming process defined in ~~claim 9~~ the ninth aspect of the invention, in addition to the effects provided in the nanocrystal layer forming process defined in ~~claim 8~~ the eighth aspect of the invention, the machining operation using the machining tool is performed, such that the material temperature at the machined surface of the workpiece is held within the predetermined temperature range, and such that the material temperature at a non-nanocrystal layer located in the lower layer portion of the machined surface or located in the surface layer portion in neighborhood of the machined surface is held at least about 500 C° for the length of time that is not larger than about 1 second, for providing the nanocrystal layer with the hardness that is about 80 % as high as the hardness of the substrate of the workpiece.

[0050] In the nanocrystal layer forming process defined in ~~claim 10~~ the tenth aspect of the invention, since the nanocrystal layer is formed in the surface layer portion of the machined surface by performing the machining operation using the machining tool, it is possible to restrain the problems, encountered in the conventional techniques, that portions of a workpiece in which the nanocrystal layer can be formed are limited depending upon a shape of the workpiece and that the thickness and characteristics of the nanocrystal layer are not uniform, Consequently, the nanocrystal layer

forming process provides an effect that makes it possible to stably form the nanocrystal layer forming process in the workpiece such as a machine component.

[0052] Further, in the conventional nanocrystal layer forming process, where the nanocrystal layer is to be formed over a wide area, the collision of the protrusion or the hard particles has to be repeated a plurality of times, thereby increasing a required forming time and resulting in inefficiency in the formation of the nanocrystal layer. On the other hand, in the nanocrystal layer forming process defined in ~~claim 1~~ the eighth aspect of the invention, since the nanocrystal layer is formed by performing the machining operation using the machining tool, it is possible to efficiently form the nanocrystal layer, leading to the consequent reduction in the cost for the formation of the nanocrystal layer.

[0053] In the nanocrystal layer forming process defined in ~~claim 11~~ the eleventh aspect of the invention, in addition to the effects provided in the nanocrystal layer forming process defined in ~~claim 10~~ the tenth aspect of the invention, the machining operation using the machining tool causes the machined surface of the workpiece to be subjected to the plastic working that causes the machined surface of the workpiece to have the true strain of at least 7, and is performed with the material temperature at the machined

surface of the workpiece being held not higher than the predetermined upper limit temperature. Thus, there is an effect that the nanocrystal layer can be assuredly formed in the surface layer portion of the machined surface of the workpiece.

[0054] In the nanocrystal layer forming process defined in ~~claim 12~~ the twelfth aspect of the invention, in addition to the effects provided in the nanocrystal layer forming process defined in ~~claim 11~~ the eleventh aspect of the invention, the machining operation using the machining tool is performed with the material temperature at the machined surface of the workpiece being held such that the overall time-based average value of the material temperature during the machining operation and the overall surface-based average value of the material temperature in the entirety of the machined surface over which the heat is distributed are not higher than the predetermined upper limit temperature. That is, the material temperature may be increased to be momentarily or locally higher than the predetermined upper limit temperature, as long as the overall time-based and overall surface-based average values of the material temperature are held not higher than the predetermined upper limit temperature. It is therefore possible to reduce a cost required for controlling the material temperature, thereby

providing an effect that restrains the cost for the formation of the nanocrystal layer.

[0055] In the nanocrystal layer forming process defined in ~~claim 13~~ the thirteenth aspect of the invention, in addition to the effects provided in the nanocrystal layer forming process defined in any one of ~~claims 8-12~~ the eighth through twelfth aspects of the invention, the machining operation using the machining tool is performed such that the strain gradient of at least 1 / ìm is imparted to the surface layer portion of the machined surface. Thus, there is an effect that the nanocrystal layer can be assuredly formed in the surface layer portion of the machined surface of the workpiece.

[0056] In the machine component defined in ~~claim 14~~ the fourteenth aspect of the invention, the surface layer portion is at least partially provided by the nanocrystal layer formed by the nanocrystal layer forming process defined in any one of ~~claims 8-13~~ the eighth through thirteenth aspects of the invention. Thus, it is possible to improve a surface hardness of the machine component, and to improve a fatigue strength of the machine component owing to a compressive residual stress imparted thereto. Further, a wear resistance of the machine component can be improved, since it becomes hard to be recrystallized even under a high temperature. Consequently,

there is an effect that makes it possible to improve the characteristics of the machine component.

[0057] Further, since the nanocrystal layer is formed by the nanocrystal layer forming process defined in any one of ~~claims 8-13~~ the eighth through thirteenth aspects of the invention, the nanocrystal layer can be formed at a low cost, there is an effect that a cost for the entirety of the machine component as a product can be restrained owing to the formation of the nanocrystal layer at the low cost.

[0058] In the machine component producing process defined in ~~claim 15~~ the fifteenth aspect of the invention, since there is provided at least the nanocrystal layer forming step of forming the nanocrystal layer in the machine component through the nanocrystal layer forming process defined in any one of ~~claims 8-13~~ the eighth through thirteenth aspects of the invention, there is an effect that the machine component can be produced with the nanocrystal layer being stably formed at a restrained cost.

[0059]

[Fig. 1] A set of views explaining an ultrafine crystal layer forming process in a first embodiment of the present invention, wherein view (a) is a cross section view of a workpiece when the workpiece is subjected to a drilling operation by a drill, and view (b) is a cross sectional view of the workpiece after the drilling operation.

[Fig. 2] A view showing a cutting condition as a first machining condition.

[Fig. 3] A view showing a cross section of a structure of a portion of the workpiece surrounding a hole.

[Fig. 4] A view explaining an ultrafine crystal layer forming process in a second embodiment, and a perspective view of the workpiece during a cutting operation by an endmill.

[Fig. 5] A set of views explaining an ultrafine crystal layer forming process in a third embodiment, wherein view (a) is a perspective view of the workpiece during a slide machining operation by a pressing tool P, while view (b) is a transverse cross-sectional view of the workpiece taken along line ~~Vb-Vb~~ 5(b)-5(b) in view (a).

[Fig. 6] A set of views explaining a nanocrystal layer forming process in a fourth embodiment, wherein view (a) is a cross section view of a workpiece when the workpiece is subjected to a drilling operation by the drill, and view (b) is a cross sectional view of the workpiece after the drilling operation.

[Fig. 7] A view showing a cutting condition as a fourth machining condition.

[Fig. 8] A view showing a cross section of a structure of a portion of the workpiece surrounding a hole.

[Fig. 9] A photograph view showing the cross section of the structure of the portion of the workpiece surrounding the hole.

[Fig. 10] A schematic view schematically showing the cross section of the structure of Fig. 9.

[Fig. 11] A set of view wherein view (a) shows a relationship between a depth measured from the surface of the hole and a crystal displacement, view (b) shows a relationship between the depth and a shearing strain, and view (c) shows a relationship between the depth and a strain gradient.

[Fig. 12] A view explaining a nanocrystal layer forming process in a fifth embodiment, and is a perspective view of the workpiece during a cutting operation by an endmill.

[Fig. 13] A set of views explaining a nanocrystal layer forming process in a sixth embodiment, wherein view (a) is a cross section view of a workpiece when the workpiece is subjected to a drilling operation by a drill, and view (b) is a cross sectional view of the workpiece after the drilling operation.

[Fig. 14] A view showing a cutting condition as a sixth machining condition, as compared with a conventional cutting condition.

[Fig. 15] A set of views explaining a nanocrystal layer forming process in a seventh embodiment, wherein view (a) is a perspective view of the workpiece during a slide machining operation by a pressing tool P, while view (b) is a transverse cross-sectional view of the workpiece taken along line ~~XIVb-XIVb~~ 15(b)-15(b) in view (a).

[Fig. 16] A schematic view showing a conventional nanocrystal layer or the like forming process (shot peening).

[0062] The ultrafine crystal refers to a crystal having a grain size (length) of from 100 nm to 1 ìm. The ultrafine crystal layer refers to a structure including the ultrafine crystal that is constituted by at least 50 % of the crystal structure. The term "ultrafine crystal layer" recited in any one of ~~claims 1-7~~ the first through seventh aspects of the invention has the same meaning.

[0086] The second layer 12 is considered as a region that was formed by a static recrystallization caused by heating up to about 700 °C during the drilling operation with the drill D (i.e., a region that was tempered upon thermal influence during the drilling operation). It is noted that the second layer 12 corresponds to "the non-ultrafine crystal layer which is provided by a lower layer portion of the machined surface" recited in ~~claim 5~~ the fifth aspect of the invention.

[0105] The third cutting condition is provided by a condition that a material temperature at a machined outer circumferential surface 21 is held lower than a predetermined temperature (hereinafter referred to as "upper limit temperature") during the ~~drilling operation with the drill D~~ slide machining operation with the pressing tool P. That is, the material temperature at the machined outer circumferential surface 21 is restrained from being increased, by adjusting an

amount of supply of a coolant to a machining portion and a rotation speed of the workpiece W.

[0119] In the above-described first through third embodiments, there have been described cases in each of which the workpiece W is constituted by the steel material. However, the workpiece W does not necessarily have to be constituted by the steel material, but may be constituted by any one of the other metallic materials other than the steel material. As the other metallic materials, there can be enumerated, for example, aluminum, magnesium, titanium, copper, and any combinations thereof. That is, the metallic material recited in any one of ~~claims 1-7~~ the first through seventh aspects of the invention is not limited to any one of the steel materials and metallic materials enumerated herein, but is interpreted to encompass various kinds of metallic materials.

[0121] The nanocrystal refers to a crystal having a grain size (length) of not larger 100 nm. The nanocrystal layer refers to a structure including the nanocrystal that is constituted by at least 50 % of the crystal structure. The term "nanocrystal layer" recited in any one of ~~claims 8-15~~ the eighth through fifteenth aspects of the invention has the same meaning.

[0145] In the second layer 32, there was observed an ultrafine crystal layer in which its grain size was about 100 nm. In this ultrafine crystal layer, it was confirmed that its

hardness was increased to 1000 Hv. It is considered that the second layer ~~12~~ 32 was recrystallized in α phase by heat applied thereto ~~after~~ during the machining operation and then residue α was caused to have an island-like shape in a further heated phase, i.e., (α+γ) two-phases region, and that eventually solid solution γ containing carbon was transformed to (α+ martensite) during cooling. It is noted that a plastic deformation with true strain of not smaller than 1 (and smaller than 7) was imparted to the second layer 32.

[0147] The third layer 33 is considered as a region that was formed by a static recrystallization caused by heating up to about 700 °C during the drilling operation with the drill D (i.e., a region that was tempered upon thermal influence during the drilling operation). It is noted that the third layer 33 corresponds to "the non-nanocrystal layer which is provided by a lower layer portion of the machined surface" recited in ~~claim 9~~ the ninth aspect of the invention.

[0154] However, the strain gradient recited in ~~claim 13~~ the thirteenth aspect of the invention is not necessarily limited to the shearing strain, and is interpreted to encompass a compressive strain and a tensile strain in addition to the shearing stress. That is, in machining operations other than the drilling operation by the drill D, the strain (deformation) of the surface layer portion of the machined surface is different in form. Thus, in the other

machining operations, there is a case where the strain of the surface layer portion principally corresponds to the compressive or tensile strain. In such a case, the "strain gradient of at least 1/μm" recited in ~~claim 13~~ the thirteenth aspect of the invention is interpreted to mean also the gradient of the compressive or tensile strain being of at least 1/μm".

[0158] The cross section shown in Figs. 9 and 10 is ~~perpendicular~~ parallel to a feed direction of the drill D. A virtual line Lz is a virtual line perpendicular to a cutting direction. The depth z is measured along the virtual line Lz from the surface of the hole 1 as an original point. The displacement x is measured along a direction perpendicular to the virtual line Lz.

[0182] In the above-described fourth and fifth embodiments, there have been described cases in each of which the workpiece W is constituted by the steel material. However, the workpiece W does not necessarily have to be constituted by the steel material, but may be constituted by any one of the other metallic materials other than the steel material. As the other metallic materials, there can be enumerated, for example, aluminum, magnesium, titanium, copper, and any combinations thereof. That is, the metallic material recited in any one of ~~claims 1-4~~ the eighth through thirteenth aspects of the invention is not limited to any one of the steel

materials and metallic materials enumerated herein, but is interpreted to encompass various kinds of metallic materials.

[0217] In the above-described sixth and seventh embodiments, there have been described cases in each of which the workpiece W is constituted by the steel material. However, the workpiece W does not necessarily have to be constituted by the steel material, but may be constituted by any one of the other metallic materials other than the steel material. As the other metallic materials, there can be enumerated, for example, aluminum, magnesium, titanium, copper, and any combinations thereof. That is, the metallic material recited in any one of ~~claims 1-5~~ the eighth through thirteenth aspects of the invention is not limited to any one of the steel materials and metallic materials enumerated herein, but is interpreted to encompass various kinds of metallic materials.